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A logarithmic amplifier using non-linear silicon diodes

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THE BRITISH BROADCASTING CORPORATION
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A LOGARITHMIC AMPLIFIER USING NON-LINEAR SILICON DIODES

Technological Report No. B-056/2
(1964/52)

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SUMMARY

The principle of the construction of a logarithmic amplifier using semi-conductor Germanium diodes as logarithmic elements was described in Report B-056, Serial No. 1953/14. This report describes an amplifier using currently available silicon junction diodes.

1. INTRODUCTION

Report B-056 described a logarithmic amplifier designed and used by the Acoustics Section of Research Department.

This amplifier depended entirely for its law upon the fact that an accurate logarithmic voltage-current relationship existed in the GEX 66 Germanium point contact diode.

Shockley[1] has shown that the current Ip through a semi-conductor diode due to a voltage V is given by

$$Ip = Ips\ (e^{\epsilon V/kT} - 1) \qquad (1)$$

where Ips is the diffusion current at zero voltage, ϵ is the charge on an electron, k is Boltzmann's constant and T the absolute temperature

Whence $$V = \frac{kT}{\epsilon} \log_e (Ip/Ips + 1) \qquad (2)$$

If $Ip \gg Ips$, the relationship between V and Ip/Ips becomes substantially logarithmic; it is found that most semi-conductor diodes possess near-logarithmic characteristics over a limited range.

At the time the logarithmic amplifier described in Report B-056 was designed, only the GEX 66 had a logarithmic law over a 60 dB range, as required for acoustic measurements.

The GEX 66 was primarily intended by the manufacturers as a low impedance v.h.f. mixer diode, and no claims were advanced for its logarithmic characteristics. Such characteristics were, in fact, found by Research Department, but only in early production batches.

With the re-design of the Acoustics Section portable oscilloscope, it became necessary to ensure that the logarithmic amplifier which is incorporated in the oscilloscope as a plug-in unit (see photograph, Fig. 1) should use currently produced diodes, the most promising type available being the SX 640. This is a non-linear silicon junction diode specifically marketed as a logarithmic conversion element. If fed from a suitably high source impedance, the SX 640 will produce an approximation to a logarithmic law over a range of 80 dB, as shown in Fig. 2, and by selection within the manufacturers' production spread it is possible to find diodes giving a more nearly logarithmic law over a less extended range.

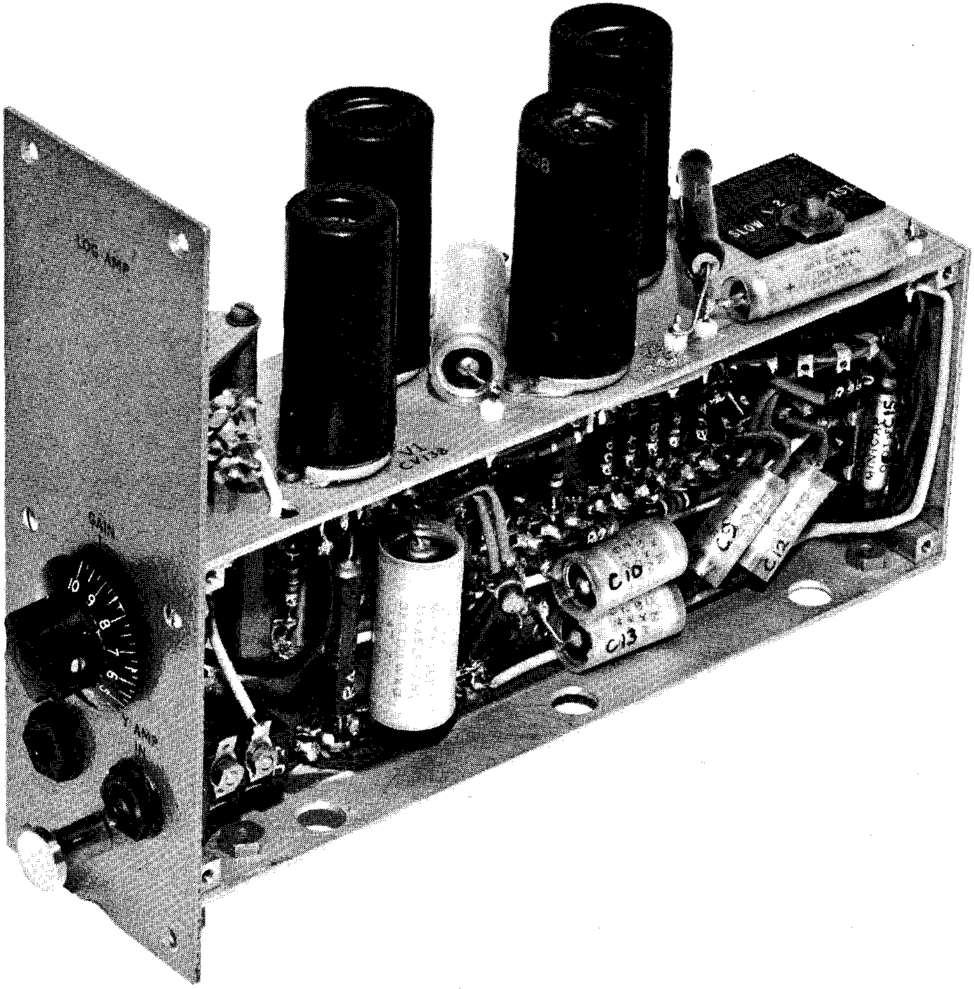

Fig. 1 - Photograph of the logarithmic amplifier designed as plug-in unit for oscilloscope

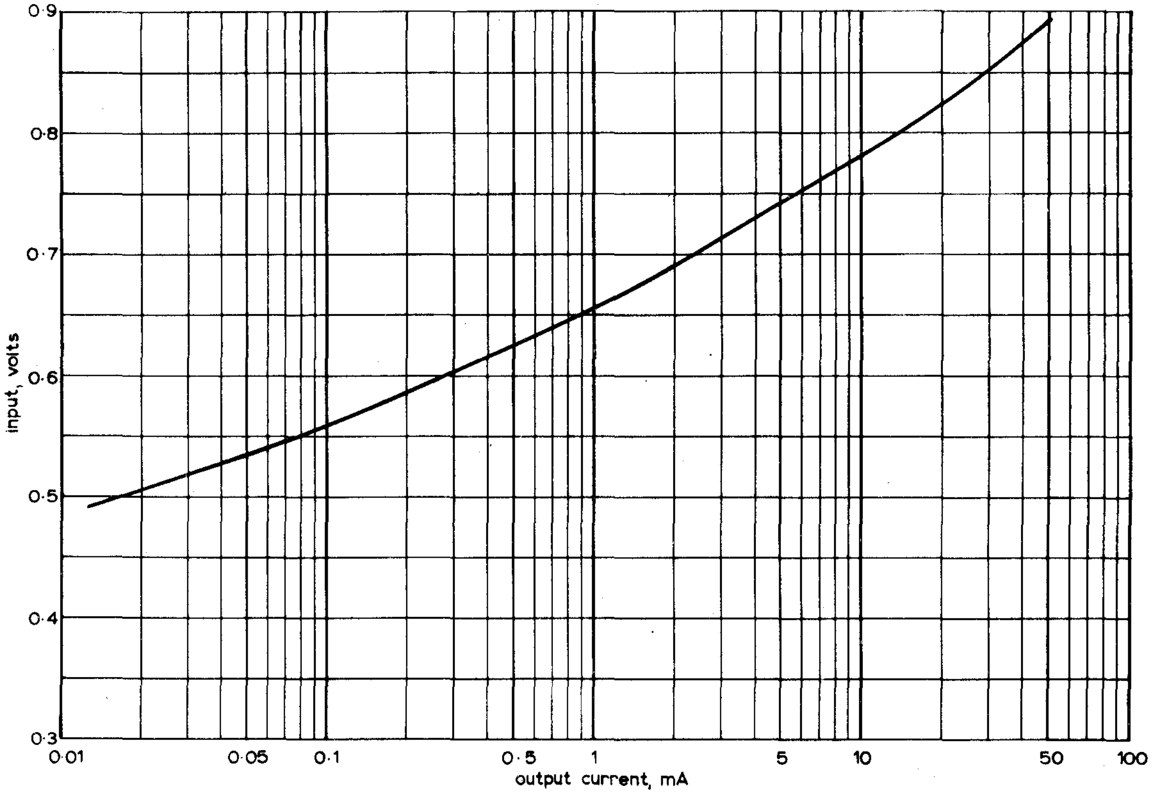

Fig. 2 - Voltage/current characteristic of SX 640 diode

It is a fundamental requirement of this type of logarithmic element that the current through the element shall be substantially independent of the change in resistance of the element itself if the logarithmic law is to be maintained. This implies a high source impedance, and consequently a high-voltage driving circuit.

In the case of the SX 640, to achieve a range of 65 dB a maximum forward current of 10 mA and a source impedance of 200 KΩ represent the optimum compromise between driving power and source impedance. With conventional circuits a high voltage line of 2 kV would be required. Various forms of feedback circuit have been designed to avoid the need for so high a voltage and the circuit finally adopted is shown in Fig. 3.

2. THE CIRCUIT

In this circuit V1 and V2A form the driver stage for the logarithmic elements MR1 and MR2. V2A is the anode load of V1, the anode impedance of V2A being increased by the current feedback developed across R4. V3A and V3B form a conventional amplifier and anode follower respectively, feeding cathode followers V4A and V4B in antiphase. MR3 and MR4 produce full-wave peak-rectified output and the combination of R24 and R25 together with the switched capacitors C10 to C15 provide free decay times of 300, 600 and 1500 dB/sec. A cathode follower V2B forms an isolating stage, and a variable output level is obtainable from R28.

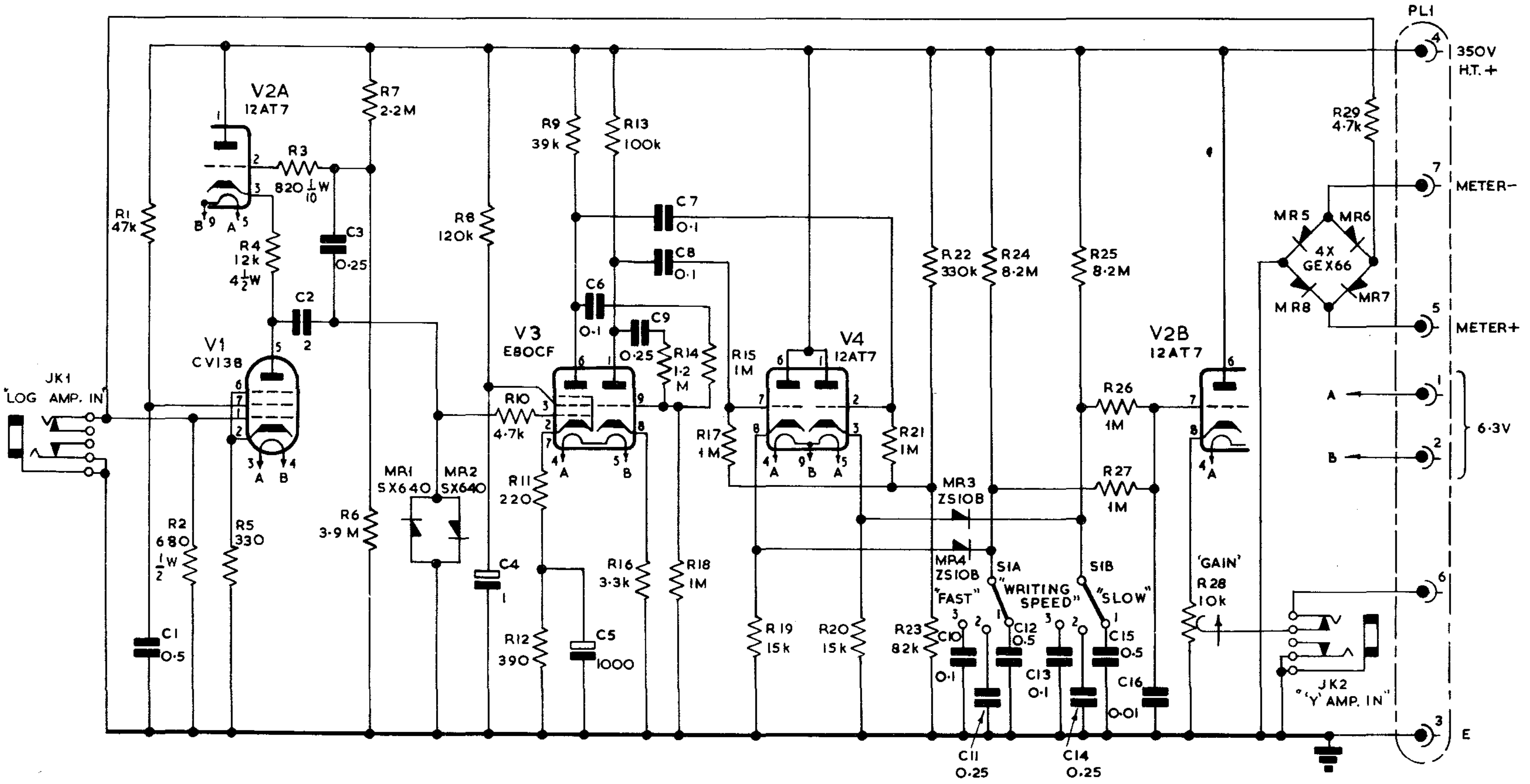

Fig. 3 - Circuit diagram of logarithmic amplifier

Overloading of the amplifier may not be visually obvious when a complex decay envelope is being displayed by the oscilloscope, and so a simple overload indicator is incorporated, consisting of a remote meter mounted in the oscilloscope front panel, fed from a bridge rectifier across the input to V1.

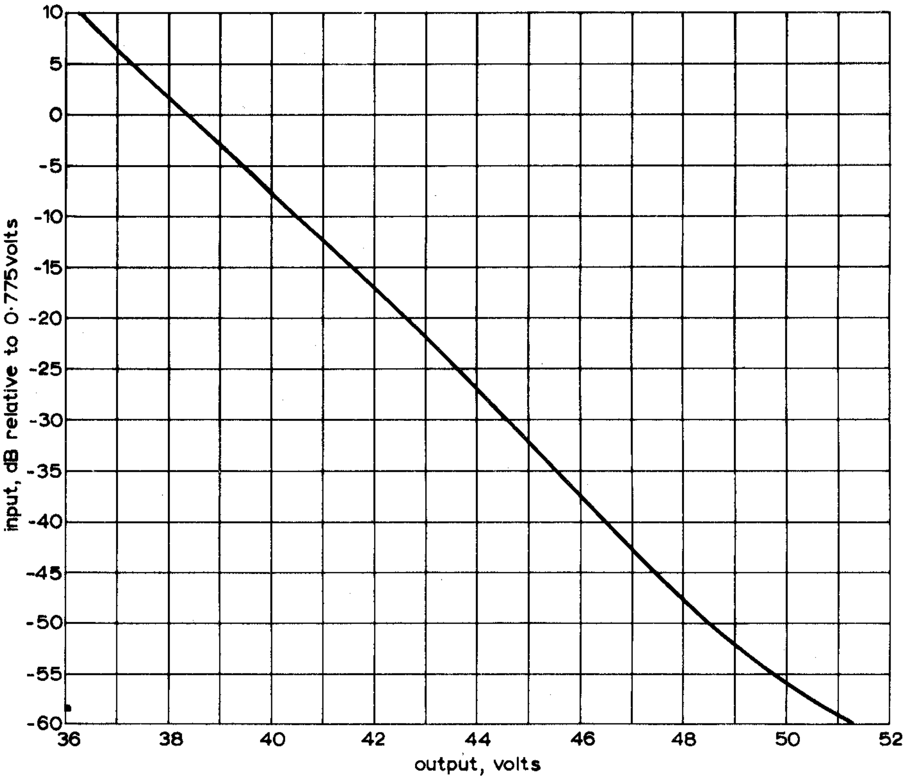

Fig. 4 - Sine wave input/d.c. output characteristic of logarithmic amplifier at 1 kc/s

The curves for 62 c/s and 8 kc/s lie wholly within ± 0·5 dB of the same line

3. PERFORMANCE OF THE CIRCUIT

Fig. 4 is a graph of the relationship between the sine wave input voltage and the d.c. output of the amplifier at 1 kc/s. From this it will be seen that a working range of 64 dB is available, which is in excess of the signal-to-noise ratio generally obtainable in studio measurements. The curves for excitations at 62 c/s and 8 kc/s, the extreme ends of the working range, lie within ± 0·5 dB of the curve in Fig. 4. As the response of the amplifier is critically dependent on the characteristics of the semi-conductor diodes it was necessary to measure the change in performance with temperature, since Equation (2) states that the input voltage V to valve V_3 will be proportional to the absolute temperature.

The amplifier was enclosed in a lagged box with a heating element and a thermometer. A staircase-decay waveform was produced by a standard Acoustics Section instrument (the rotary calibrator) consisting of a rotary attenuator made up of ten stages of 5 dB each, driven round by a synchronous motor at one of four selected speeds. This provided a stepped sine wave input to the amplifier. Measurements of temperature were taken simultaneously with photographs of the output as displayed on an oscilloscope (Fig. 5).

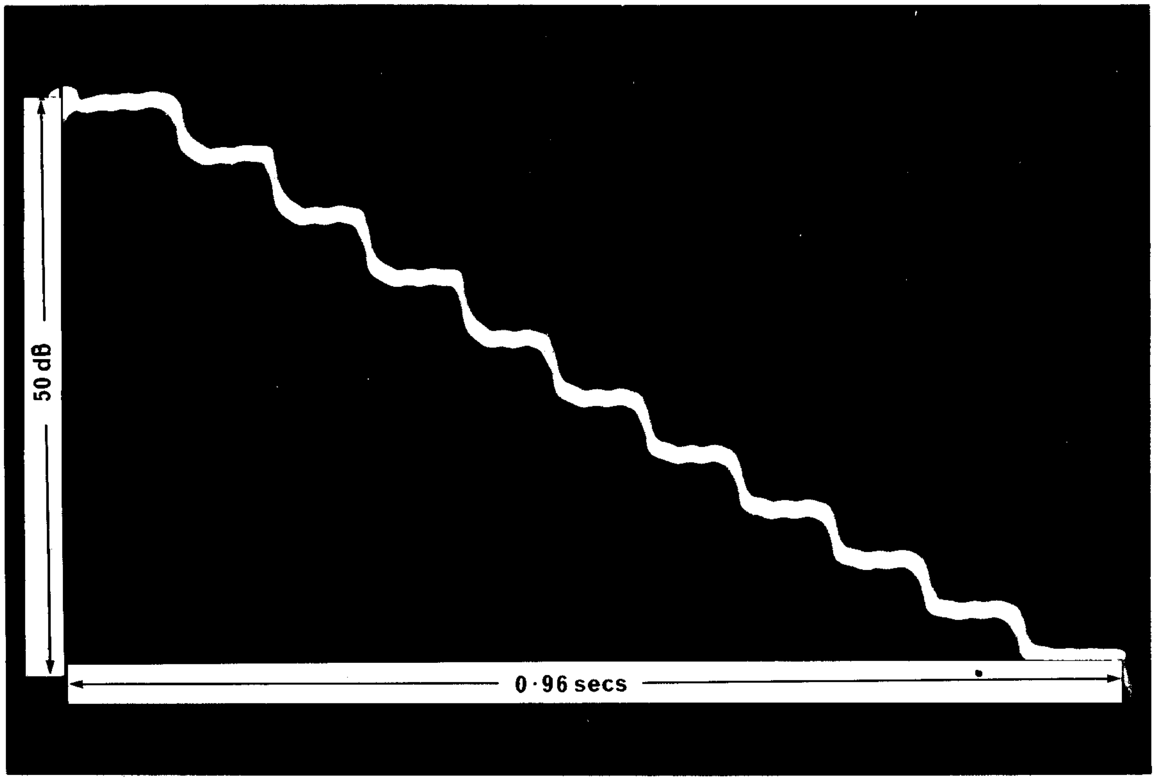

Fig. 5 - Calibration trace for temperature tests

Measurements taken over a range of 30°C and a period of 87 minutes showed that for a rise in temperature of 22°C the maximum drift, expressed as a change in slope, did not exceed 5%. For the total rise of 30°C, the change was 10%. With the normal calibration procedures, errors in measurement due to this cause do not exceed 2%.

4. SPECIFICATION

Input impedance	600Ω
Maximum input level	+12 dB rel. 1 mW in 600Ω
Maximum logarithmic range	64 dB
Output voltage change for input change of 64 dB	16 V
Pre-set writing speeds	300, 600 and 1500 dB/sec.
Weight	750 g
Power consumption	3·5 mA at 300 V 1·2 mA at 6·3 V

5. FUTURE DEVELOPMENT

Since the above unit was designed, Zimmerman and Gruschka[2] have referred to the Telefunken OA 180 as having an extended logarithmic range. The OA 180 is a gold-bonded Germanium diode, not generally available in this country, but tests on the Mullard OA 5 diode of similar type showed a promising range of logarithmic law and a simple biasing technique extended the available range to the required 60 dB.

It is not proposed at this time to supplant the existing instrument with one using OA 5 diodes but it may be noted that the OA 5 may be fed from a much lower source impedance than the SX 640. A source impedance of 50 KΩ may be used without serious degradation of the law, and the OA 5 would be suitable for use in transistorised equipment.

6. CONCLUSIONS

The instrument described satisfies the present requirements for a logarithmic converter for acoustic measurements and uses currently available components.

A very much smaller version using transistors and gold-bonded diodes is now possible, but at present would have little practical advantage over the existing instrument when used as a sub-unit in the Acoustics Section portable oscilloscope.

7. REFERENCES

1. Shockley, W., 'Electrons and Holes in Semi-conductors', D. Van Nostrand Co. New York, (1950), page 90.

2. Zimmerman, K.H. and Gruschka, H.D. 'Acustica', Vol. 11, (1961), page 180.

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